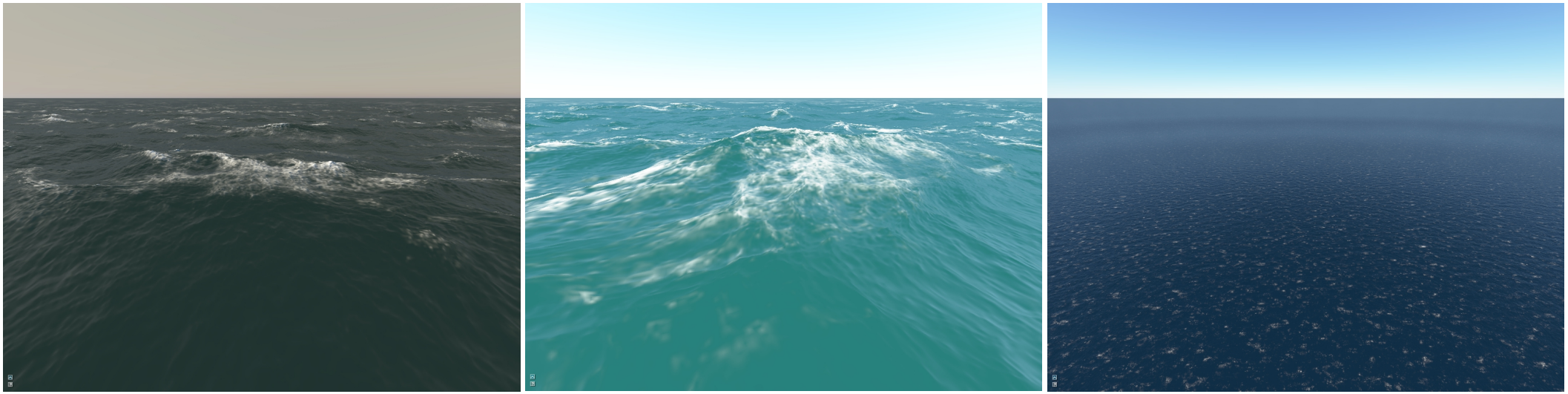
Real-time Animation and Rendering of Ocean Whitecaps



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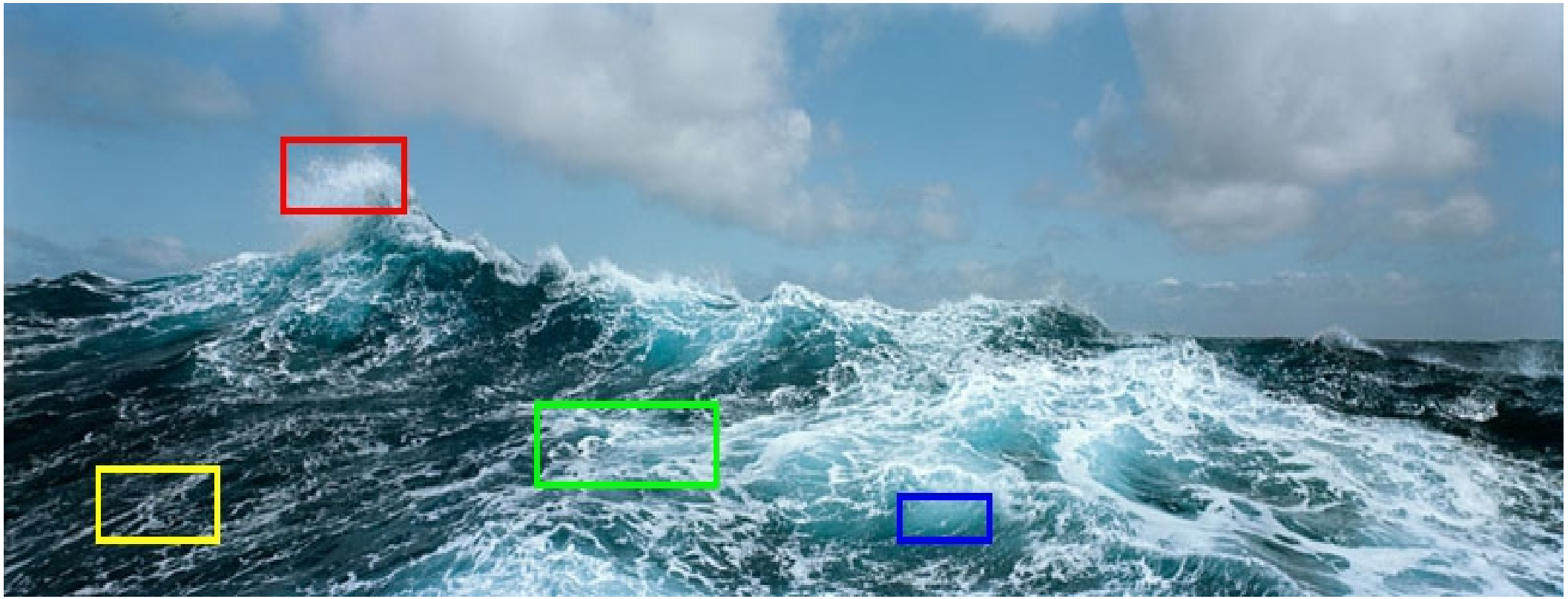
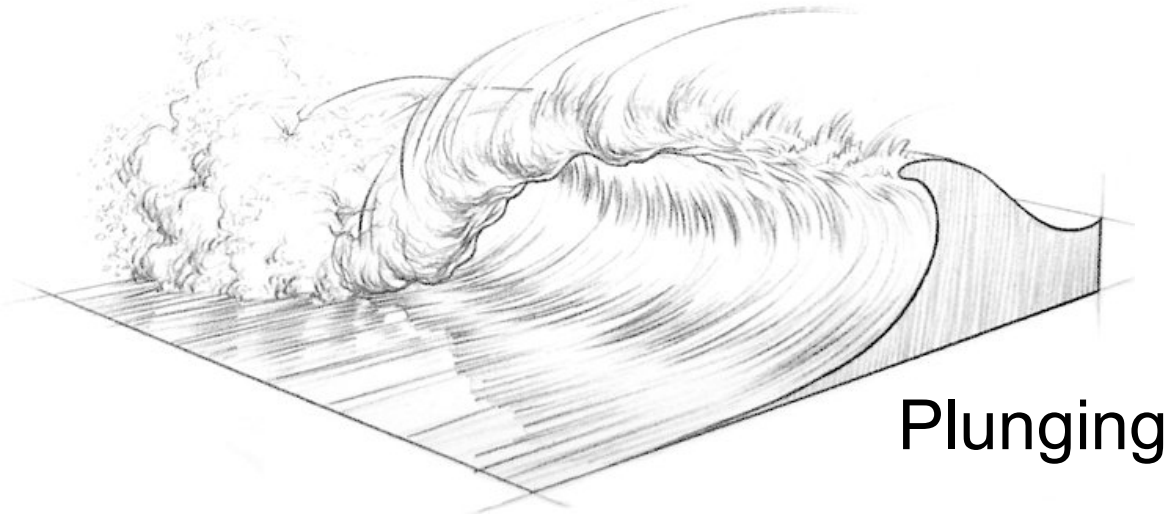
Université de Lyon, CNRS Université Lyon 1, LIRIS, UMR5205, F-69622, France

Whitecaps

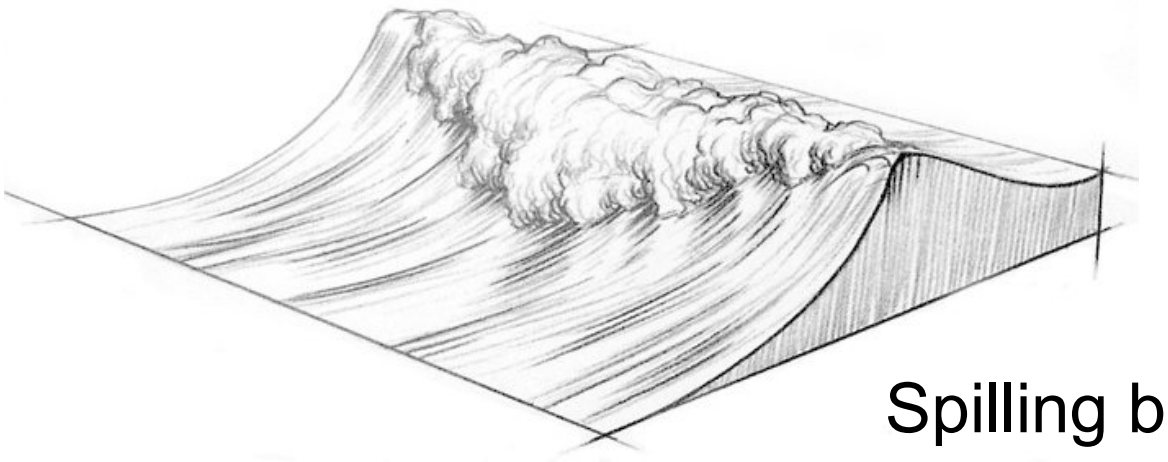


spume + **foam streaks** + **surface foam** + **bubble cloud**

Deep Water Breaking Waves



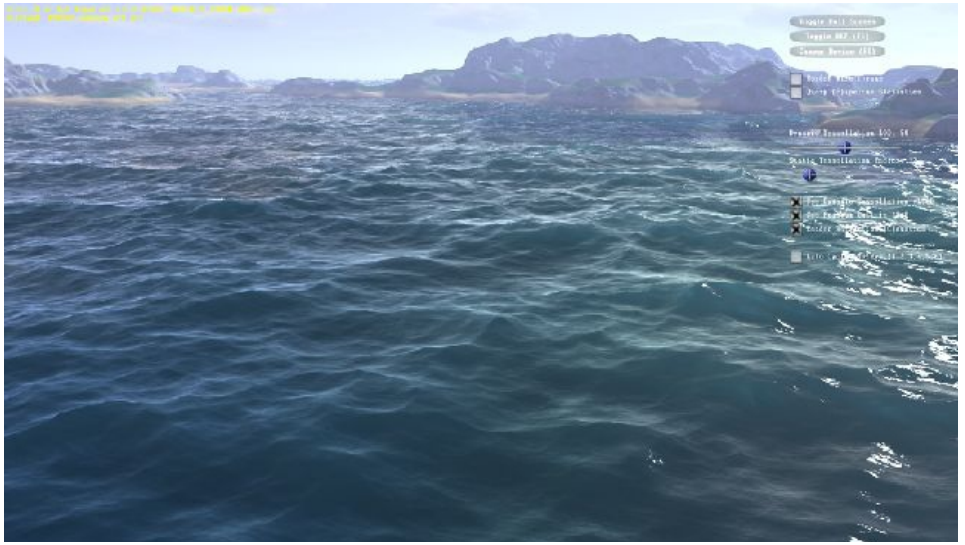
Plunging breaker



Spilling breaker

Motivation

Real time



Photographs

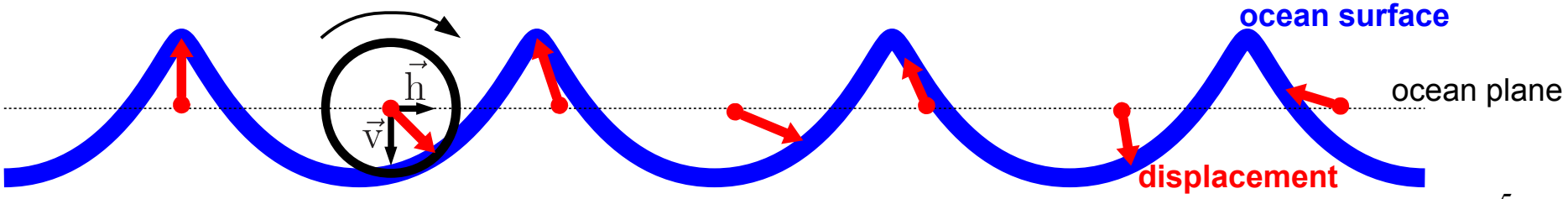
Movies

Ocean Rendering: Wave Models

Trochoidal waves

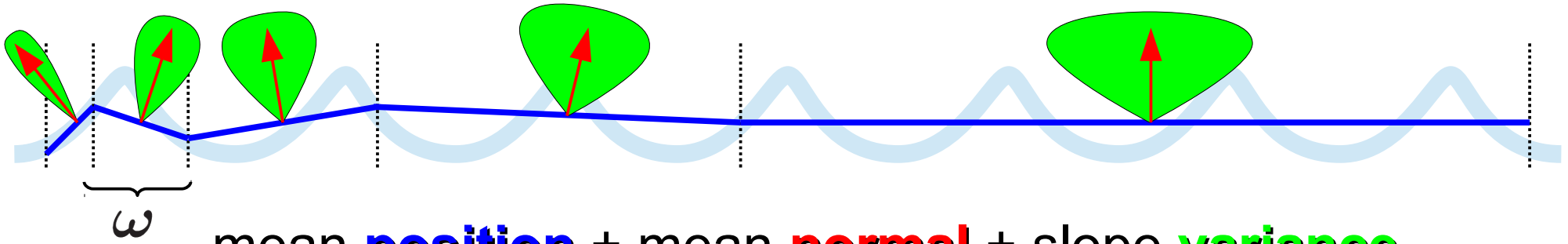
Fourier transform

ocean surface = horizontally and vertically undulated plane



Ocean Rendering: Lighting

$$\mathbf{I}(\omega) = \mathbf{I}_{\text{sun}}(\omega) + \mathbf{I}_{\text{sky}}(\omega) + \mathbf{I}_{\text{water}}(\omega)$$

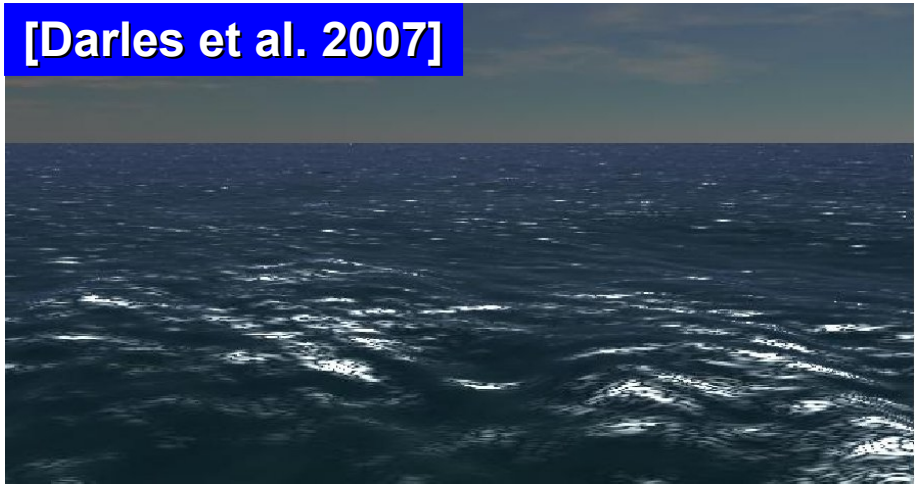


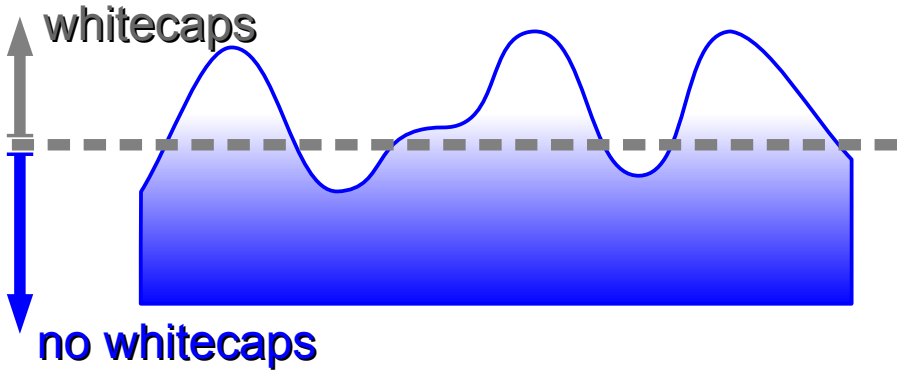
mean **position** + mean **normal** + slope **variance**

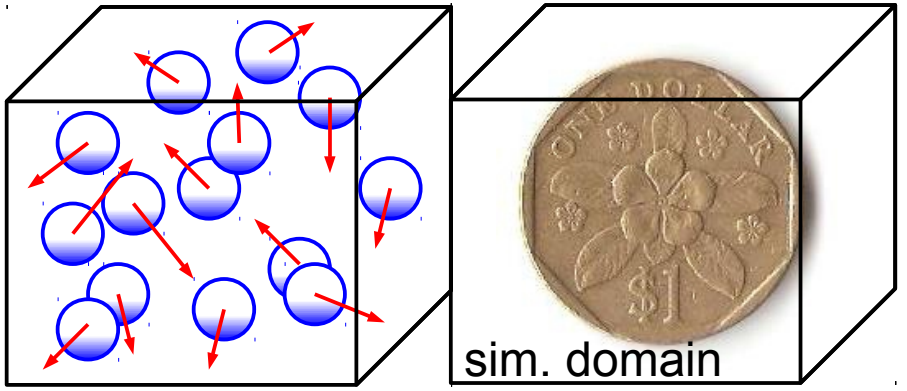
Ocean Rendering: Whitecaps

Empirical models

Particle based







low quality

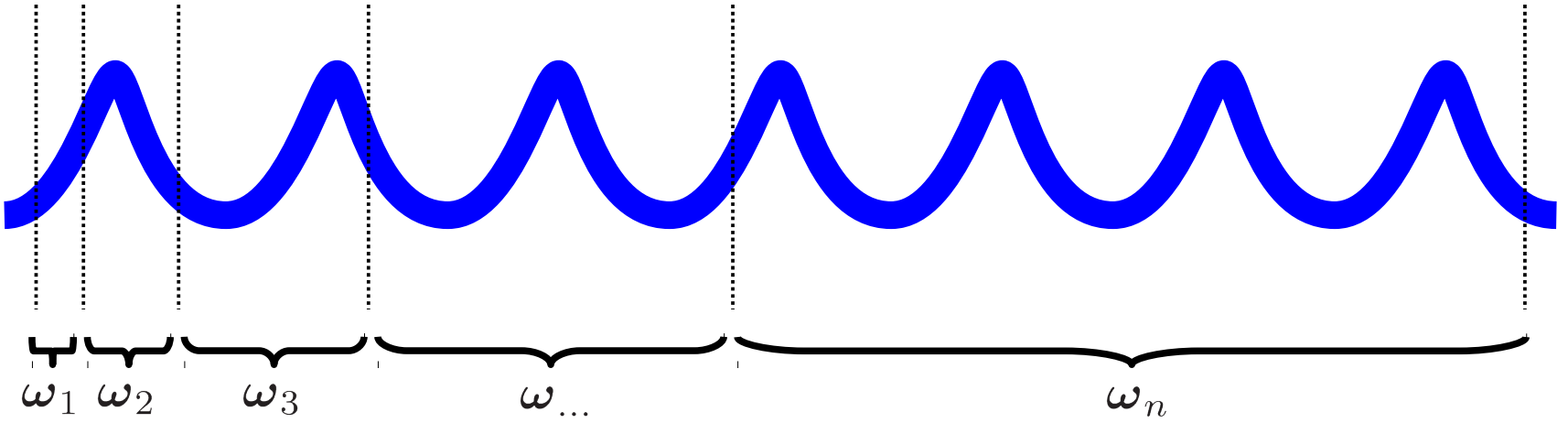
no control / slow

Objective

- Extend Bruneton's lighting model to account for whitecaps
  - Any viewpoint from ground to space
  - Seamless transitions from geometry to BRDF
  - Real time
- Context
  - Deep water waves
  - Gaussian heights and slopes
  - Spilling breakers only (no overturning)

Ocean Lighting

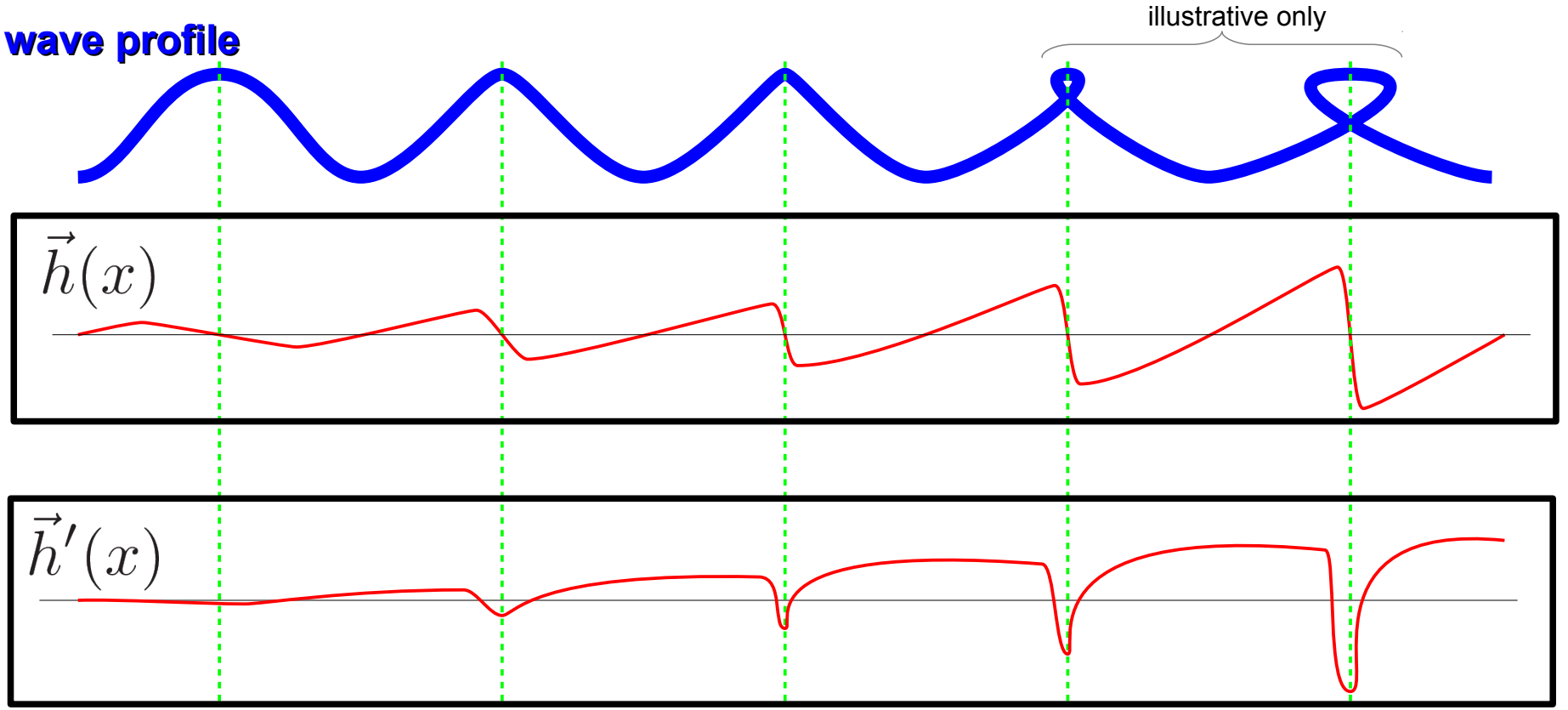
- $\mathbf{I} \approx \boxed{\mathbf{I}_{\text{sun}} + \mathbf{I}_{\text{sky}} + \mathbf{I}_{\text{water}}} + \boxed{\mathbf{I}_{\text{whitecap}}}$ [Bruneton et al. 2010]
- Whitecap radiance depends on amount of breaking waves $\mathrm{W} \Rightarrow \mathbf{I}_{\text{whitecap}} = \mathrm{W} \cdot \text{Lambert}_{0.4}$



$\Rightarrow \mathrm{W}(\omega),\ \forall \omega\ ?$

Breaking Waves

- Use surface tension
  - Proportional to jacobian of horizontal displacements



Breaking Waves

- We use

$$\mathrm{W}(\boldsymbol{\omega}) = \int_{\boldsymbol{\omega}} \mathrm{H}(\mathbf{p})\mathrm{d}\mathbf{p}, \qquad \mathrm{H}(\mathbf{p}) = \begin{cases} 1 & \text{if } \mathrm{J}(\mathbf{p}) < \alpha \\ 0 & \text{otherwise} \end{cases}$$

Breaking Waves

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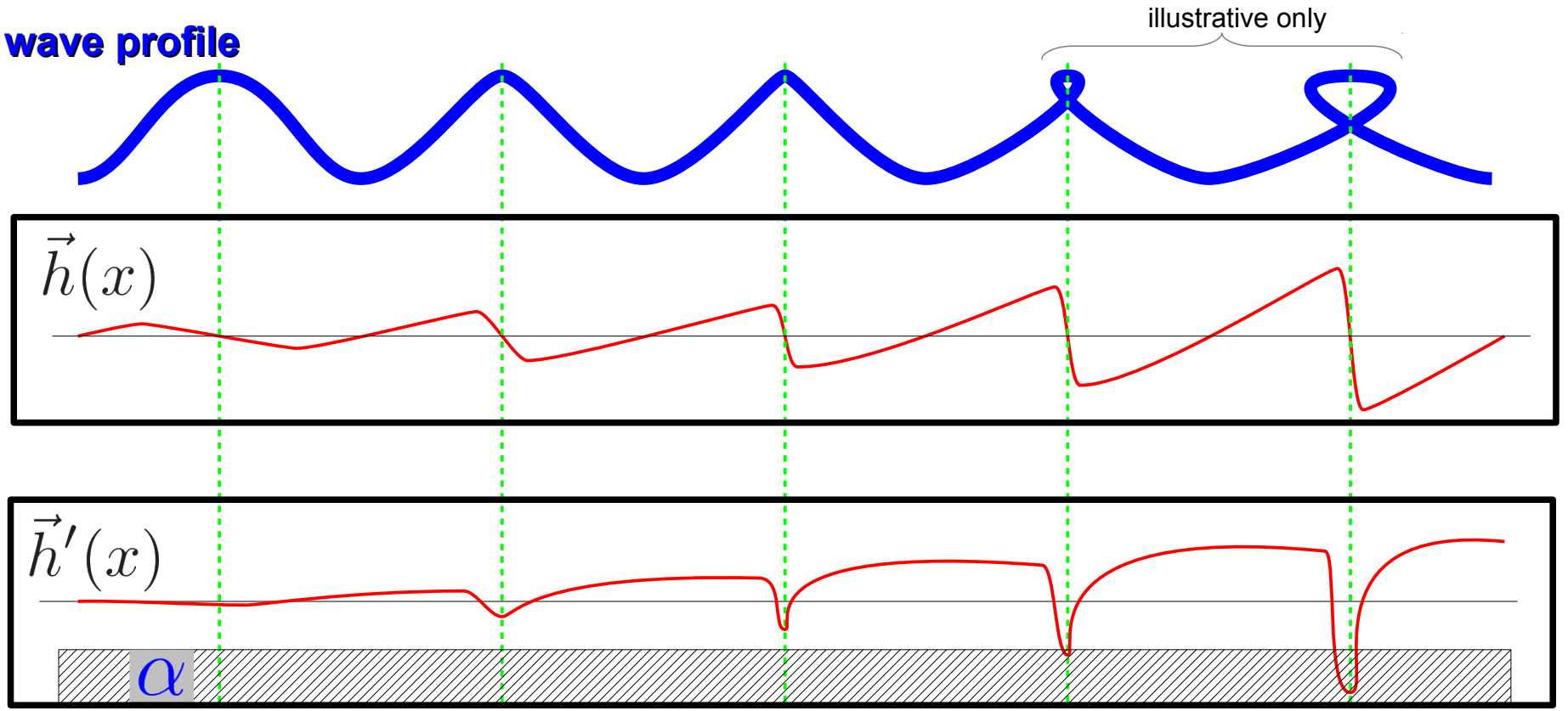
  - Proportional to jacobian of horizontal displacements



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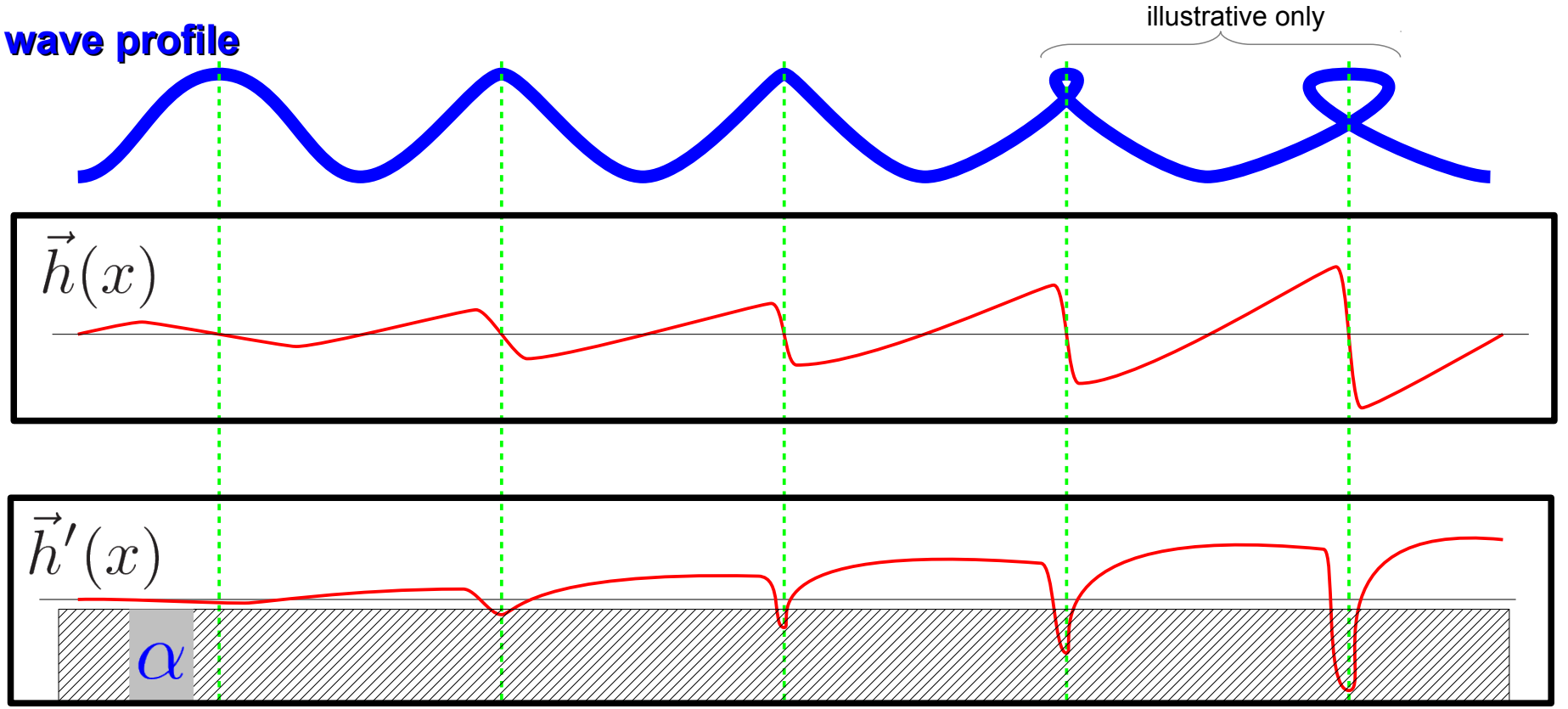

Breaking Waves

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$$\mathrm{W}(\boldsymbol{\omega}) = \int_{\boldsymbol{\omega}} \mathrm{H}(\mathbf{p})\mathrm{d}\mathbf{p}, \qquad \mathrm{H}(\mathbf{p}) = \begin{cases} 1 & \text{if } \mathrm{J}(\mathbf{p}) < \alpha \\ 0 & \text{otherwise} \end{cases}$$

- $\mathrm{H}(\mathbf{p})$ depends on Gaussian functions

$$\mathrm{W}(\boldsymbol{\omega}) \approx \frac{1}{\sqrt{2\pi\sigma_{\boldsymbol{\omega}}^2}} \int_{-\infty}^{+\infty} \mathrm{H}(\mathbf{p}) \exp\left[-\frac{(\mathrm{J}(\mathbf{p}) - \mu_{\boldsymbol{\omega}})^2}{2\sigma_{\boldsymbol{\omega}}^2}\right] \mathrm{dJ}(\mathbf{p})$$

$$= \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{\alpha - \mu_{\boldsymbol{\omega}}}{\sqrt{2\sigma_{\boldsymbol{\omega}}^2}}\right)\right]$$

$\mu_{\boldsymbol{\omega}}, \sigma_{\boldsymbol{\omega}}^2$ parameters can be computed analytically for trochoids or through hardware mipmapping for Fourier waves

Ocean Lighting

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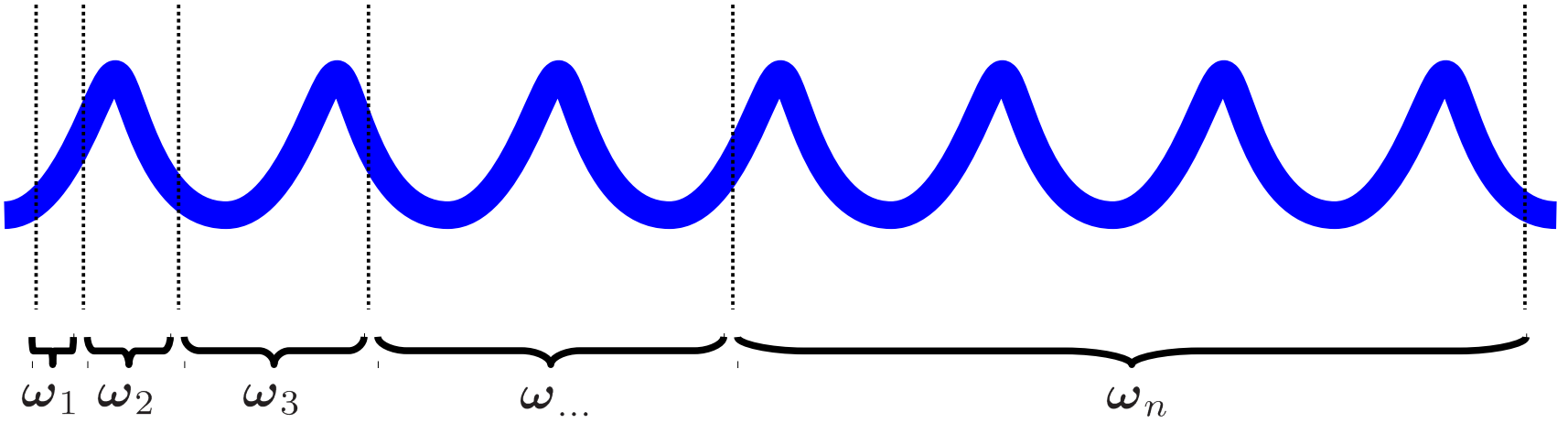

$\mathrm{W}(\omega),\ \forall\omega\,?$

Ocean Lighting

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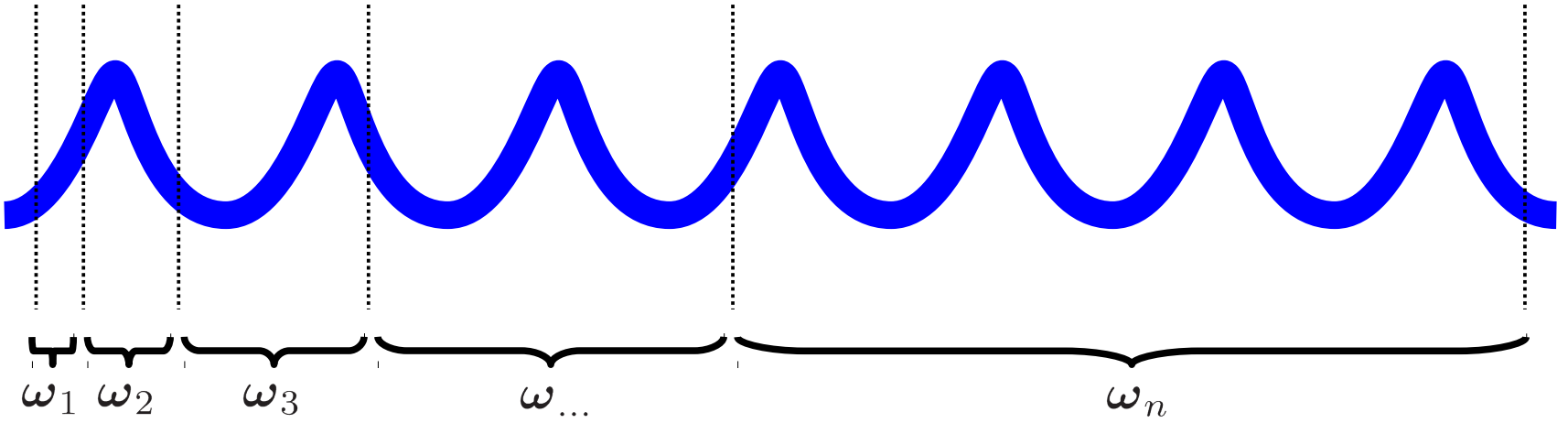
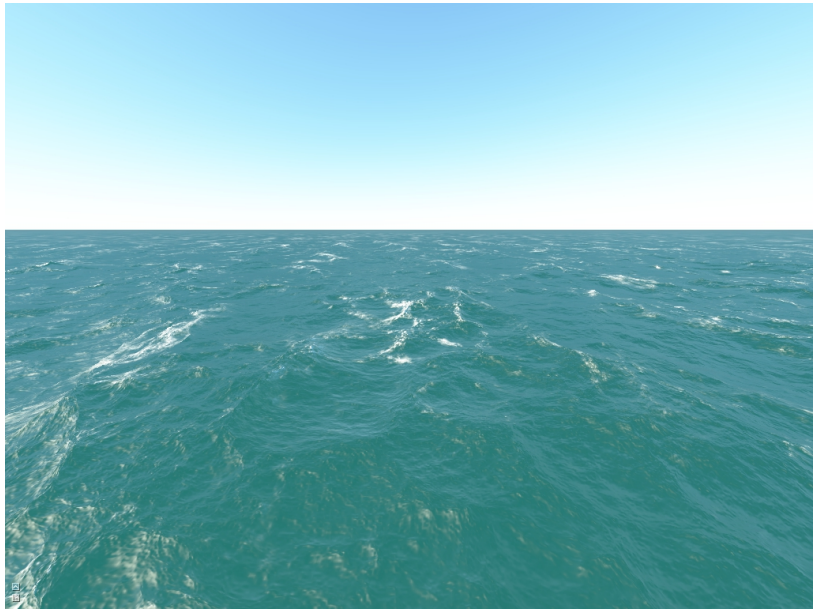


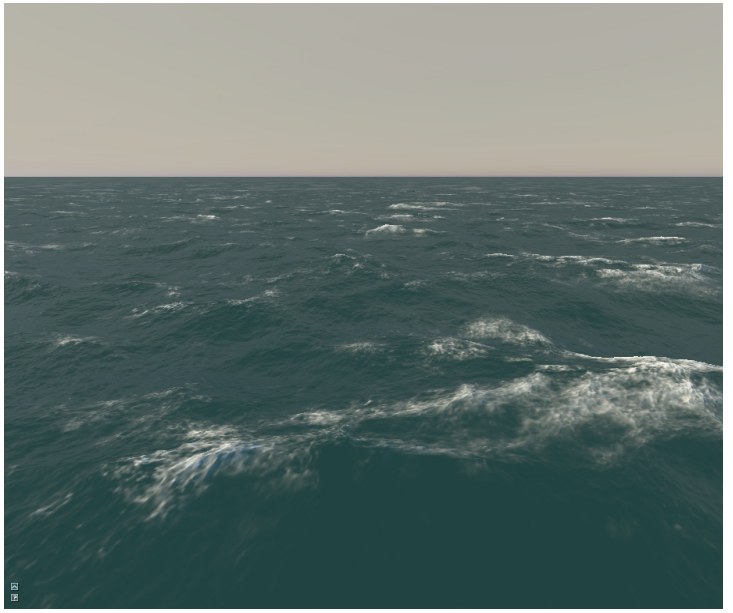
$$\Rightarrow \mathrm{W}(\omega) = \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{\alpha - \mu_\omega}{\sqrt{2\sigma_\omega^2}}\right)\right]$$

Results: Quality

real time

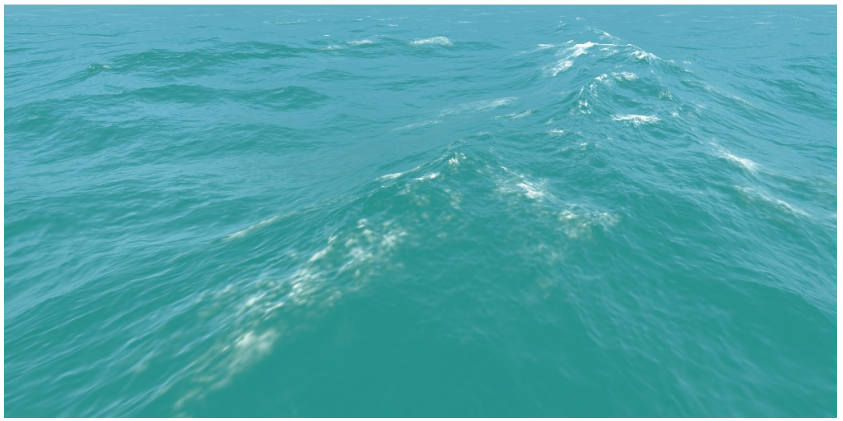
photographs



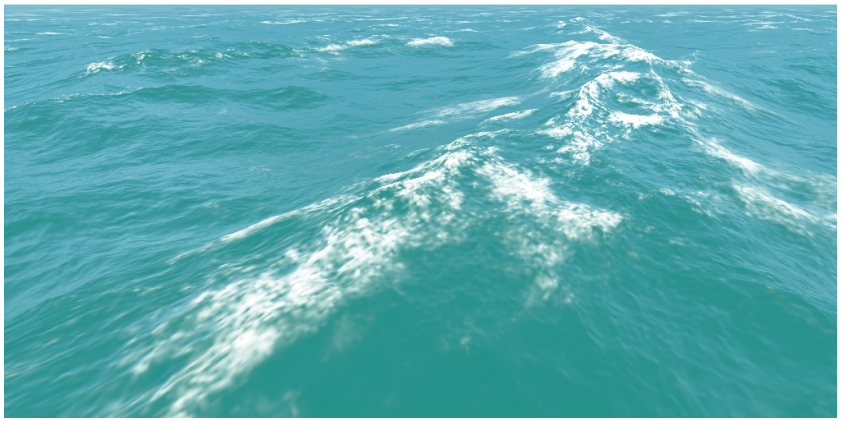


Results: Control

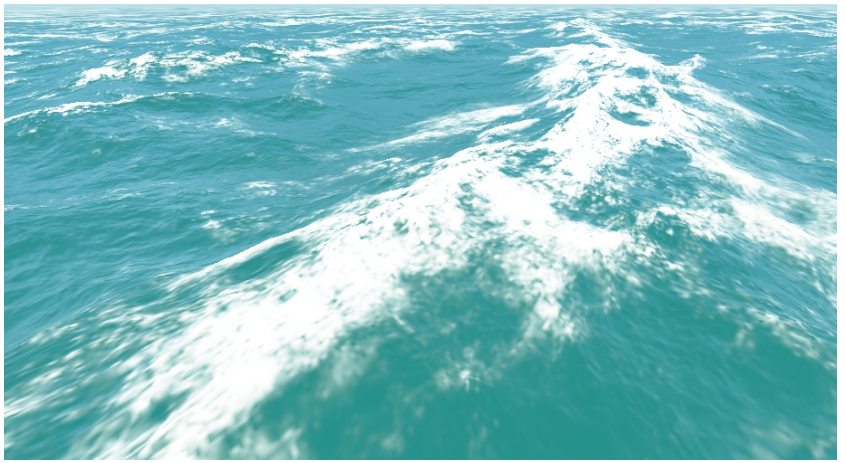
$\alpha = -0.1$



$\alpha = +0.3$

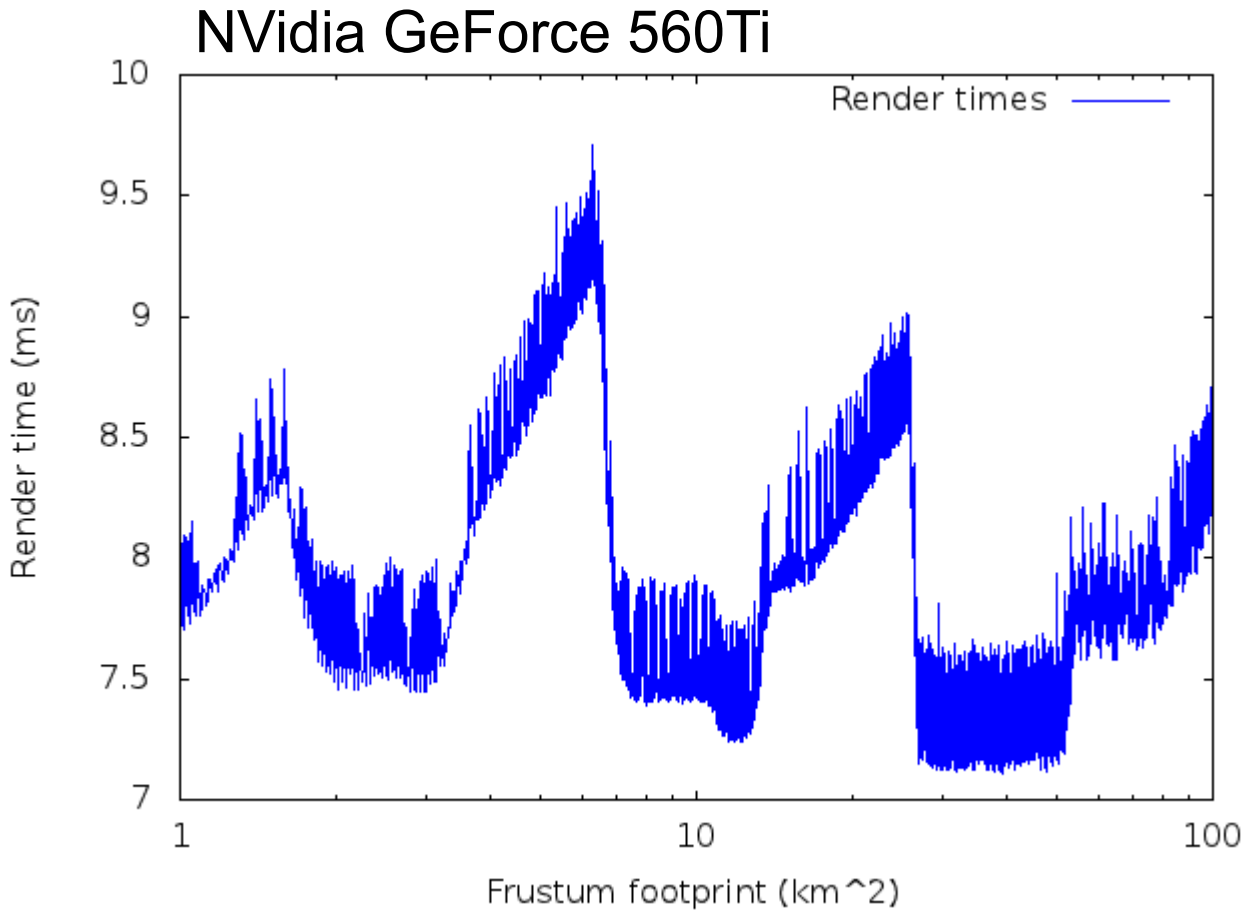


$\alpha = +0.7$



(same surface)

Results: Scalability / Real Time



Results: Limitations

- Reflectance fluctuations only
  - No impact on geometry

    ex: no plunging breakers
- No decay
  - Whitecap can last several seconds
- Analytical surface
  - Repetitive artifacts on periodic surfaces

Conclusion

- Ocean scenes with whitecaps in real time
  - Scalable performance
  - Controlable
  - Good quality
- Future work
  - Decay
  - Richer whitecap shading model (currently Lambertian / no visibility)

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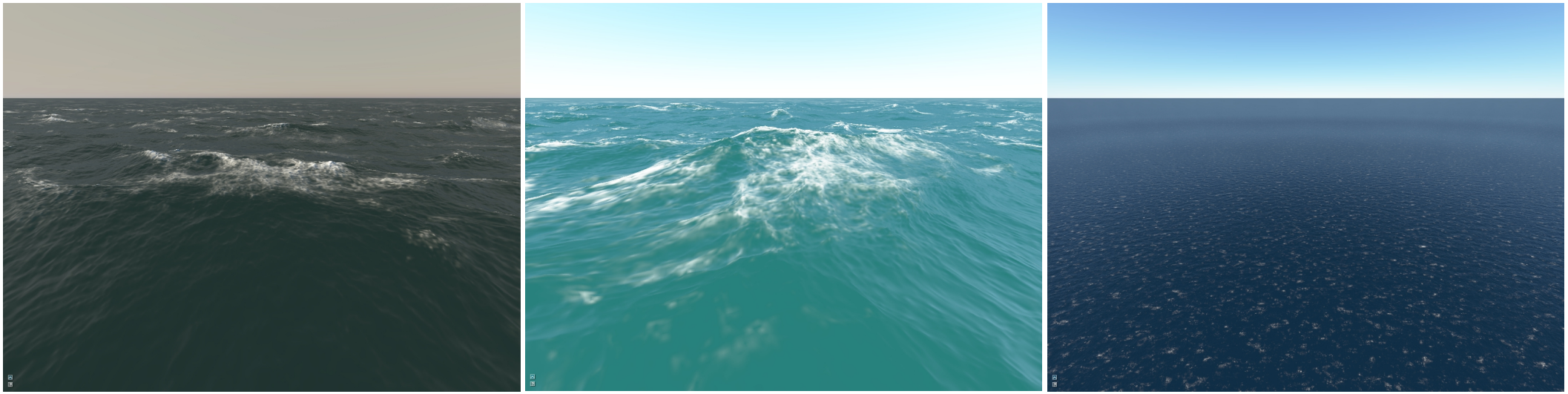

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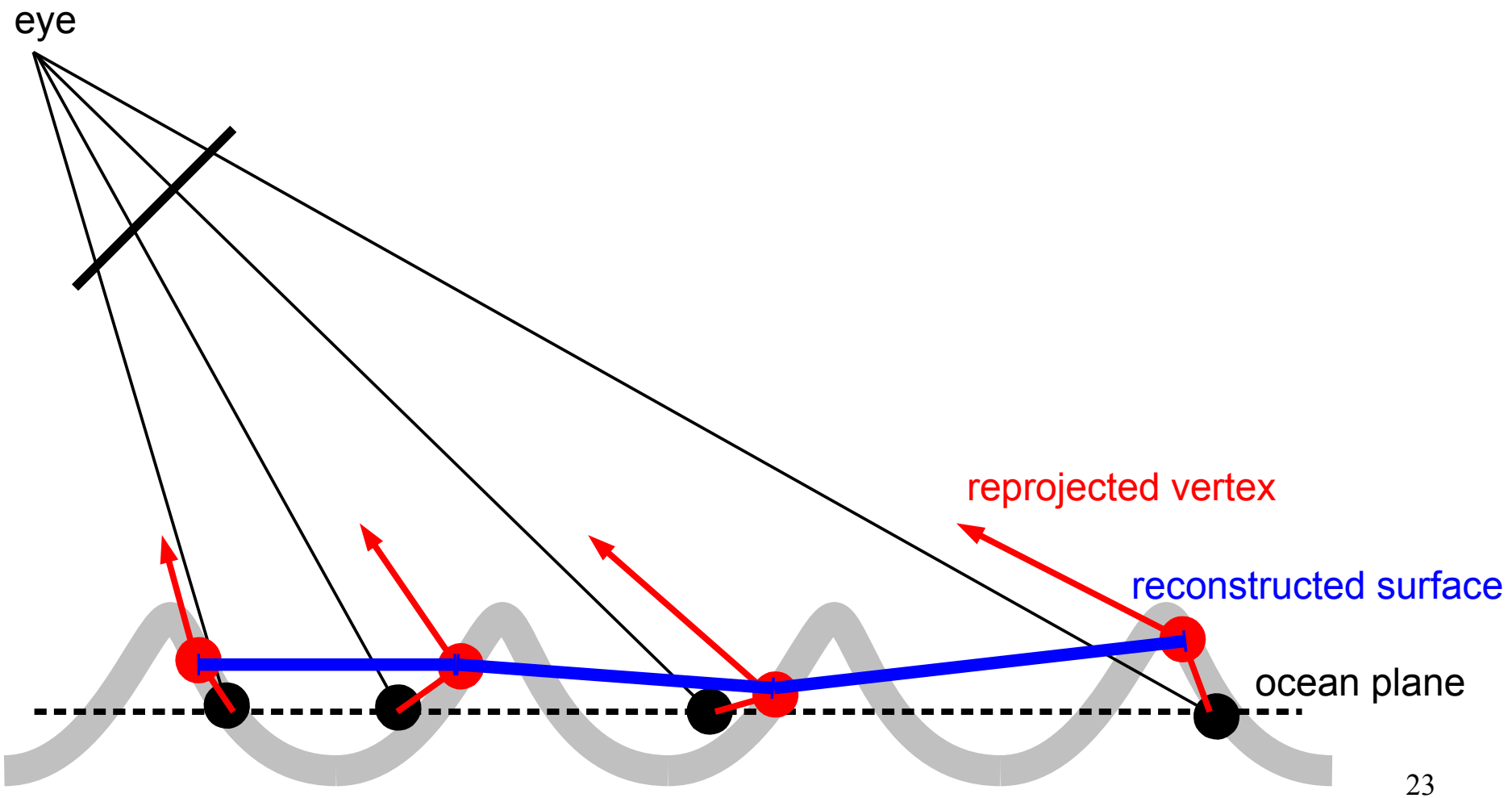
Projected Grid

- Automatic geometrical LOD



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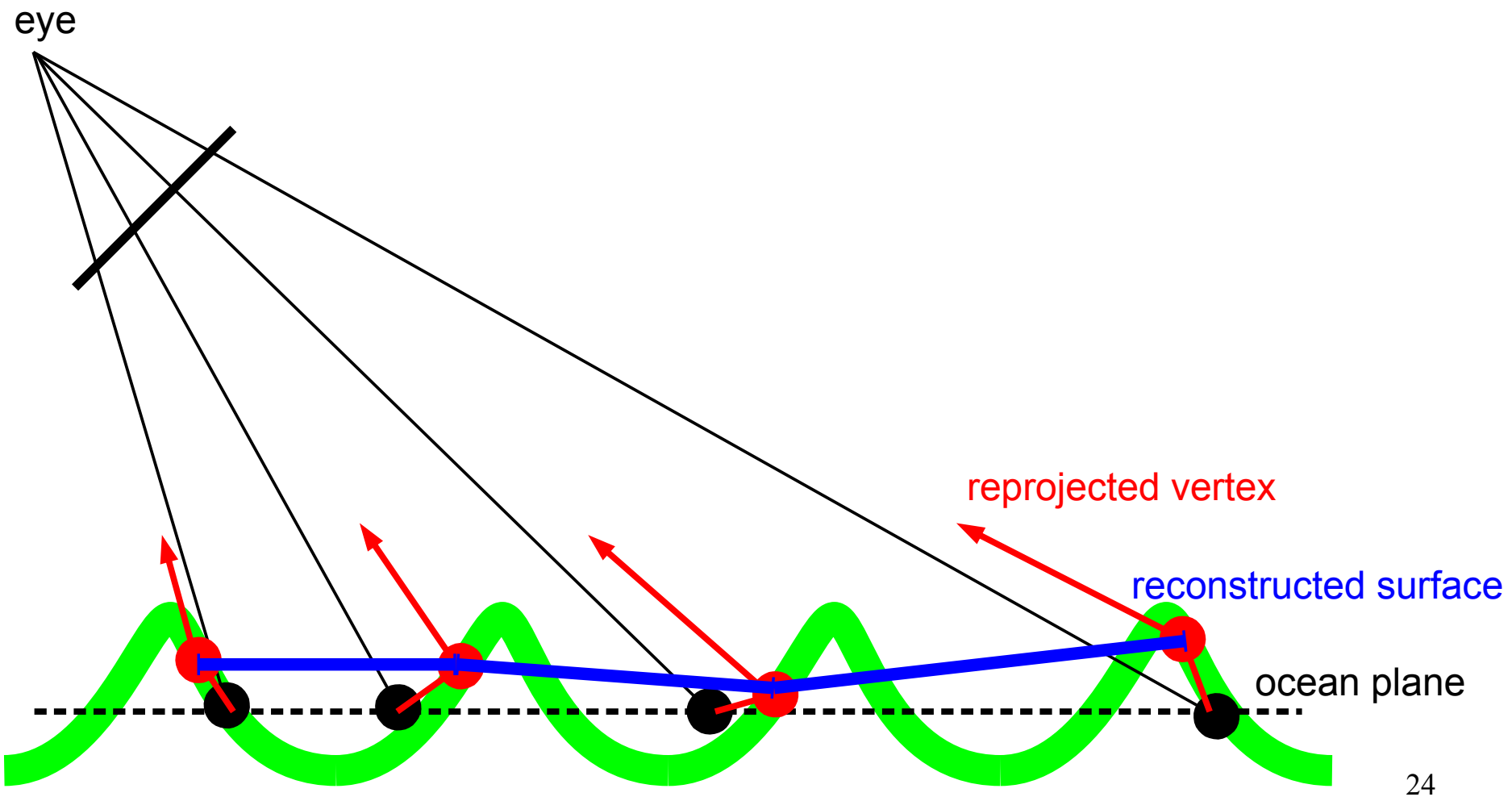
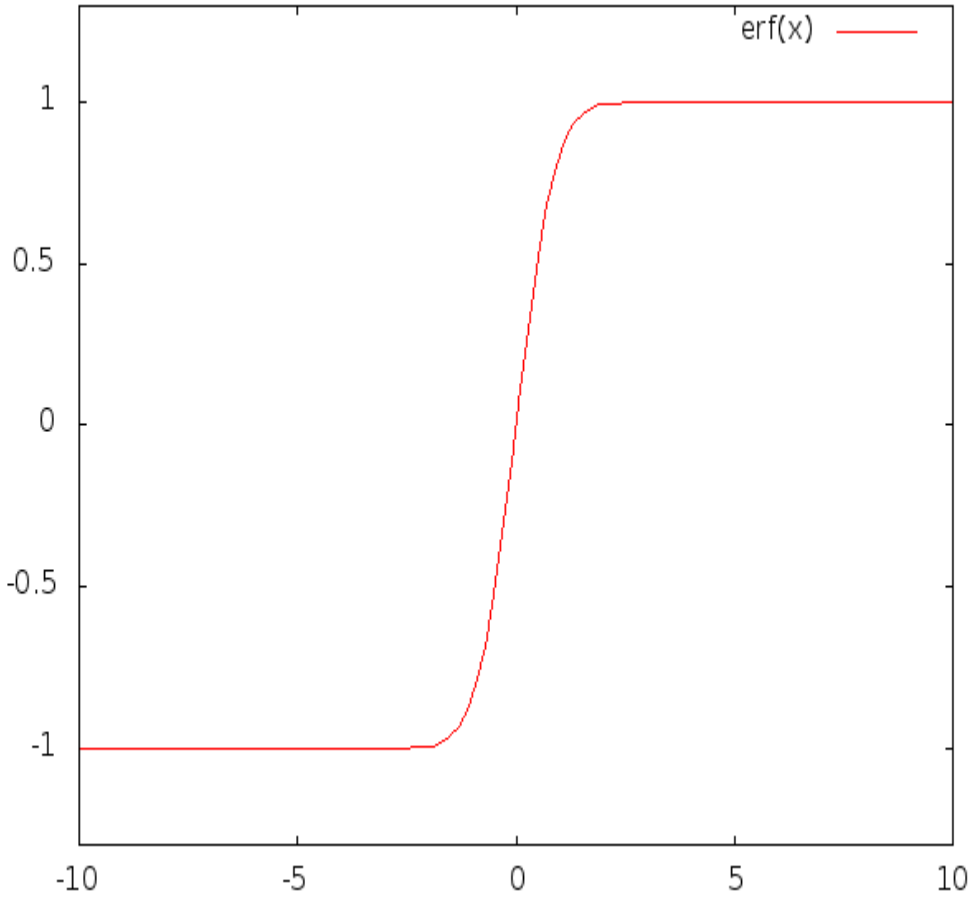
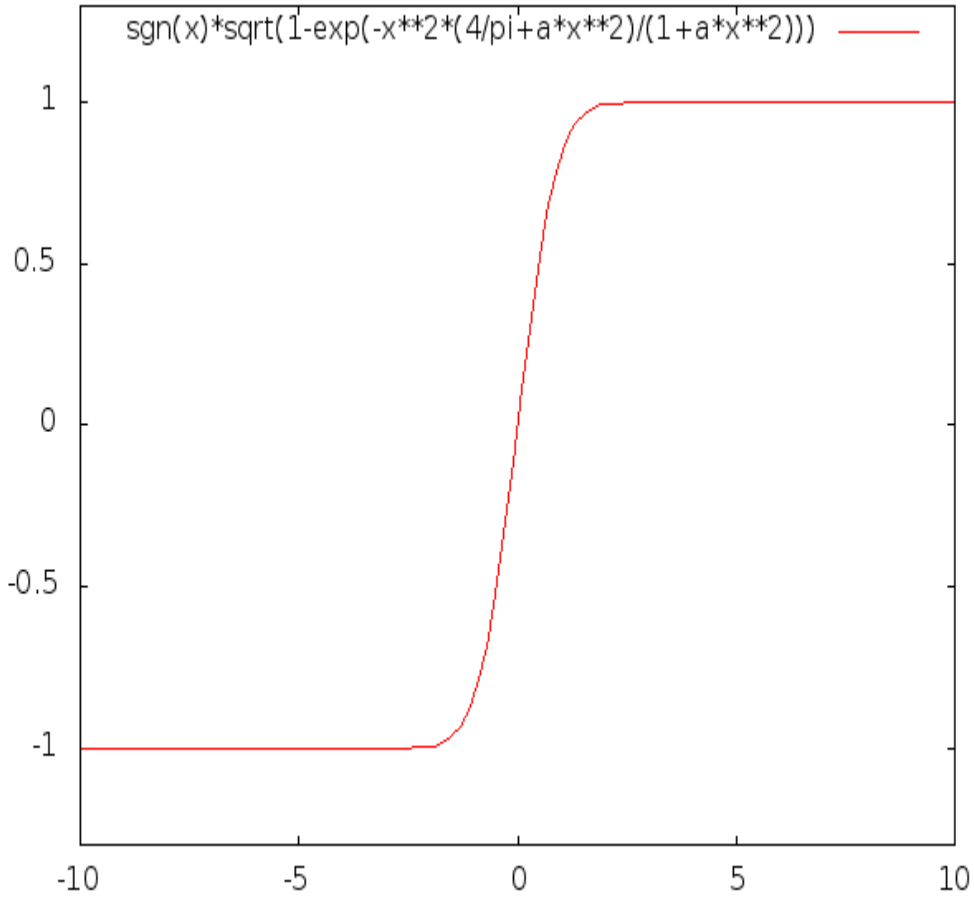


Erf: Approximation

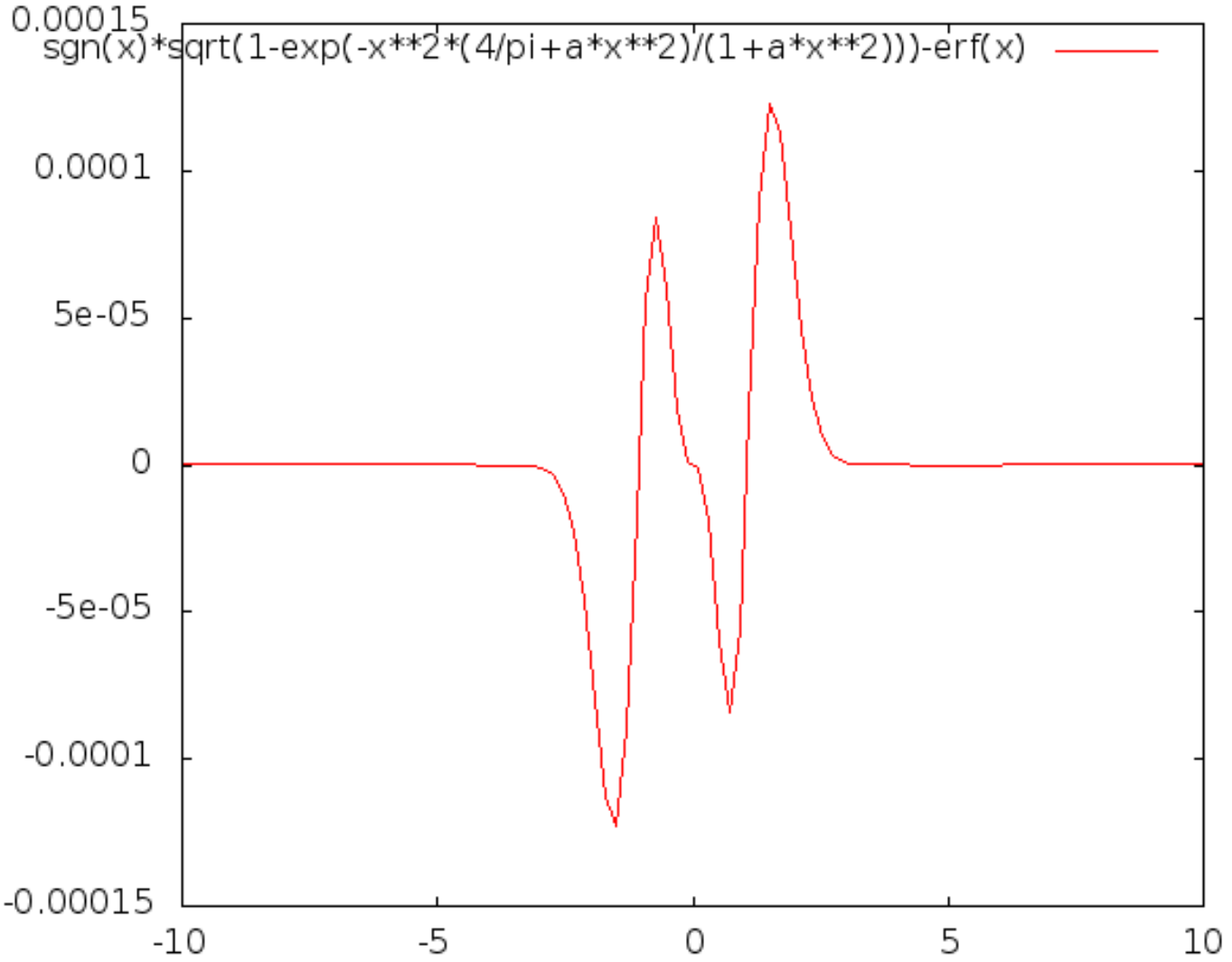


erf(x)



our approximation

Erf: Error



max error: 0.00012